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REFRACTORIES
BY PLASMA JET

A Special Ceramics Report

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the cover

The plasma jet equipment shown on the cover is being used to spray thin refractory shells of such materials as hafnium carbide at about 10,000° F. The shell is made by coating a mandrel which is rotating on a lathe. The mandrel is then removed, leaving a thin shape that may be used as a rocket nozzle liner. The method is described on pages 12-13.

Cover and other photographs in this issue by Bill Diehl

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IN BANGKOK, THAILAND, a Georgia Tech professor is currently developing a graduate program in civil engineering for students of Southeast Asian nations. In Brussels, Belgium, a former exchange student at Tech is designing power distribution systems for Europe and Asia. In Mexico City, a Tech graduate is working on plans for the further industrial development of his country.

These three examples briefly illustrate one of the least recognized traditions of this institution—its yearly export of talent. Last year 284 foreign students worked toward Georgia Tech degrees in engineering, science, architecture and industrial management. Ultimately most of these young men and women will return to their home nations to apply their knowledge.

Each year, five or six of these students are part of a program that is a unique expression of international interest. Through a student-conceived, student-run organization—the World Student Fund Committee of the Georgia Tech YMCA—these outstanding foreign students are provided with full scholarships and living expenses for an academic year on the campus. The funds for this program come from students, fraternities, faculty members, alumni and friends of Georgia Tech. To my knowledge there is no comparable program at any other university in the world.

These and most of the foreign students who come here at their own expense are especially serious, hard-working students. I think they are keenly mindful of the important roles they will play in the technological advancement of their homelands.

Thus from Latvia to Hong Kong, one should not be surprised to find professional men who speak English with a slight Southern accent. Chances are the speaker was once a student at Georgia Tech.

E. D. Harrison

President

Courtesy National Geographic and Mount Palomar Observatory

J. D. Walton, Head, Ceramics Branch, looks into space, basic research and

CERAMICS IN THE SIXTIES

THE SIXTIES should see man's efforts to conquer space expanded to a degree undreamed of a few short years ago. However, before man reaches the stars, or even the closer planets, he must solve numerous materials problems. These problems seem to us almost as difficult as reaching the stars themselves. This results from the fact that our basic knowledge of materials, and the effect of high temperatures and/or low pressures (vacuum of space) on the properties of these materials has not kept pace with the development of the technology which requires their use.

Most of the efforts to solve current high temperature materials problems have been a result of engineering and ingenuity. Combinations of materials, for instance, have provided solutions to high temperature problems that no single material could have solved. As a matter of fact there has grown out of this manipulation of materials the "materials engineer," who develops composite materials designed to take advantage of the best properties of each material without its weaknesses.

Many engineers are optimistic about the future potential of composite materials. Fiberglass reinforced plastics for ablative nose cones and metal reinforced ceramics for ramjet combustion liners are examples of the materials engineer's successes.

Although we owe many of our technological advances which depended upon the development of new high temperature materials to the materials engineer, it has been fortunate that certain operational limits were not particularly severe in each case and thus provided areas where compromises were possible. The nose cone must be exposed only once to very high temperatures (5,000 to 10,000° F) for only a matter of seconds. Therefore, the ablative system composed of fiberglass for reinforcement and plastics for ablation solved the problem. In the ramjet, the temperatures were much lower, (2,000 to 4,000° F) but the time was in terms of many cycles

of many minutes each. Therefore, a metal was used for reinforcement, and the ceramic to provide insulation and oxidation protection for the metal.

However, the high temperature problems of the future do not offer the many areas of compromise that permitted the relatively quick solution of past problems. For example, the ion engine for future space craft will require certain components which must be electrical insulators at temperatures above 2,000° F in the vacuum of space for periods of months or years. The "time barrier" referred to in astronautics literature applies to the endurance of materials as well as passengers. Of the existing high temperature materials, ceramics offer the most promise of solving such problems.

Yet the vacuum of space combined with long periods of exposure present an environment to which few materials have been exposed. We have essentially no knowledge of the behavior of any materials in such an environment. Before much is learned we will have to have satellite laboratories to evaluate and study materials under such conditions, since even the vacuum of space is difficult to produce here on earth.

Ceramics, because of their generally low vapor pressure at normal temperatures, should find ever increasing use in the conquest of space. Explorer I was partially coated with a ceramic to control the absorption of solar radiation and in turn control the internal temperature of the satellite. The ceramic was selected because of the way it reflected solar radiation and the fact that it should be stable in the vacuum of space.

The leading edges of Dynar Soar (the manned re-entry vehicle) will attain temperatures in excess of 3,000° F for many minutes at rather low pressures during the vehicle's return to earth. The temperature and time of exposure will be such that a system of a metal reinforced ceramic, similar to that developed for the ramjet, may provide a solution.

However, it will not be long before the temperature and time requirements of more advanced vehicles will be such that new materials must be developed to solve the problem. Add to this the probability that we will shortly want to enter the atmosphere of other planets and be faced with resisting chemical attack (other than oxidation) on the leading edges at high temperatures, and the demand for new materials or a better understanding of present materials becomes paramount.

The development of the nuclear rocket motor with its high temperature (5,000° F) components is already taxing existing materials to the limit. Not only will high temperatures and high velocities be encountered but high nuclear radiation as well. The components must be capable of withstanding these conditions for long periods of time if a successful motor is to be realized.

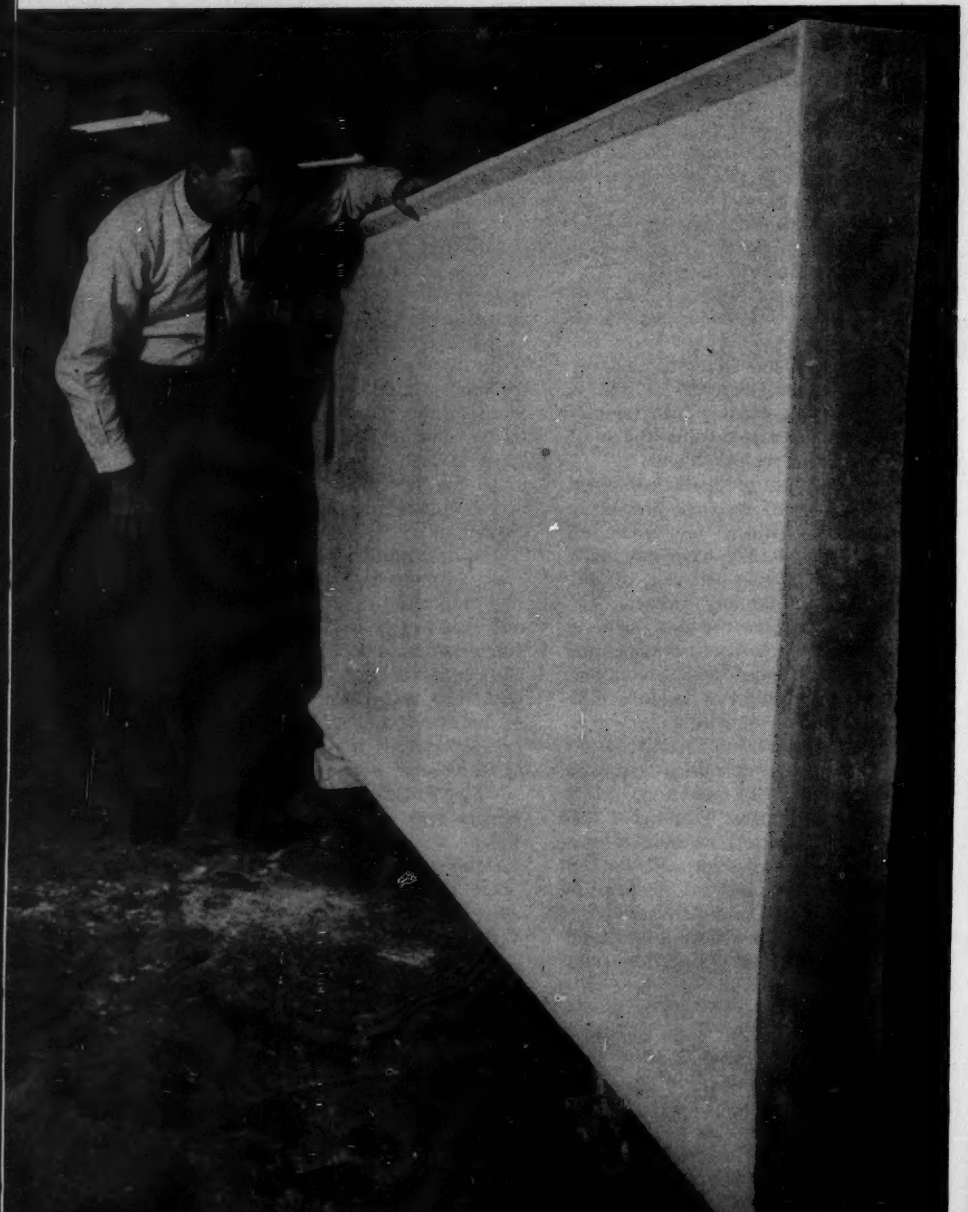
These few examples have been used to illustrate the extent to which engineers of today are stretching present materials technology to solve today's high temperature problems. Without new materials or a better understanding of materials through basic research we may find the problems of the future impossible to solve.

A Report on the Ceramics Branch

OUR ENTHUSIASM for the future of the Ceramics Branch is as great as our satisfaction in the way that our work and facilities have grown in the past. During 1959 the Ceramics Branch increased its budget to approximately $400,000. New work was undertaken in the fields of ceramic tooling and telescope reflectors while work was expanded in the nuclear and rocket materials fields.

Additional space acquired during 1959

continued on page 26



by N. E. Poulos
Assistant Head, Ceramics Branch

FUSED SILICA: THE CINDERELLA CERAMIC

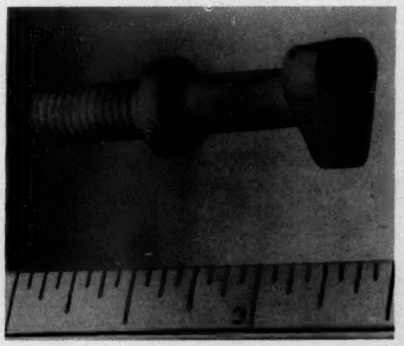
Spectacular results come from new research on an old material

THE SUCCESSFUL DEVELOPMENT of techniques for forming massive and/or complex shaped refractories from fused silica has resulted from joint efforts of an industrial sponsor and Georgia Tech. During August of 1956 the Glasrock Products Company, then known as the North Foundry Mold Company, initiated a project at the Engineering Experiment Station for the purpose of finding ways to make permanent foundry molds from fused silica.

The sponsor thought that the following method held promise in breaking through the price barrier of producing a mold to compete with sand casting: A precision casting ceramic material (fused silica grain or powder) would be used to form a thin shell, backed up by a foamed silica material. It was felt this combination would provide a permanent mold with either a permanent or renewable liner, depending upon the size or configuration of the piece to be cast. The high cost of the materials in this case would be offset by the fact that several castings could be made from one mold with a minimum of time and labor involved. During the early phases of this project it became apparent that foamed fused silica would not be available in any quantities for a long period of time.

But traditionally out of such unfortunate circumstances come new developments. In this case a new, inexpensive method of bonding the fused silica was developed and the sponsor was inspired to manufacture fused silica himself and to produce the entire mold from the bonded fused silica. Now the problem

Van Toole



Left. Hearth for heat-treating furnace is one of larger pieces cast of fused silica aggregate. *Right.* Small slip cast fused silica piece is part of instrument for a satellite. Threads were cut by machine.

LARGE BRAZING FIXTURES OF FUSED SILICA ARE EASILY SLIP-CAST.

was to develop practical and workable techniques of forming the molds into proper shapes with desired surfaces and strength.

Studies were initiated to evaluate the properties of bodies fabricated from this new source of fused silica. The properties were evaluated as functions of particle size, binders, milling and firing conditions. From these studies a fused silica slip was developed which opened the door to forming massive and/or complex shapes. (In the vernacular of ceramists, slip is a liquid suspension of finely divided particles.)

The fused silica slip is used in forming shapes by slip casting in porous molds such as plaster, or as a binder for coarse fused silica aggregate to be used in the forming of massive shapes. The accompanying illustrations indicate the range of sizes that may be achieved. The small intricate shape is to be used to house a heat sensing element in a satellite. The massive shape is being used as a hearth for a heat treating furnace.

A fused silica slip—fused silica aggregate castable mixture has been used in the fabrication of refractory boiler liners. These refractories have been in service on Diesel locomotives for over two years without replacement. The life of such liners constructed from conventional refractory bricks was 3 months.

Slip cast fused silica is being used in the steel industry for fabrication of ladle liners and pouring spout used in handling molten iron. It has also found wide use in the fabrication of investment casting molds for the production of precision cast metal parts utilizing the "lost wax" process. The most recent uses in the metal industries are involved in the handling of molten aluminum. Other areas of refractory applications for fused silica are discussed in some of the other articles of this magazine.

A fused silica foam was developed by mixing a suitable organic foaming agent with fused silica slip. The foaming agent is subsequently burned out during the firing of the foamed fused silica. The foam is light weight and has excellent thermal insulating properties for use as a refractory.

This foam is presently being used for refractory brazing forms on which honeycomb stainless steel panels are brazed. Such panels are presently being used in the construction of supersonic aircraft.

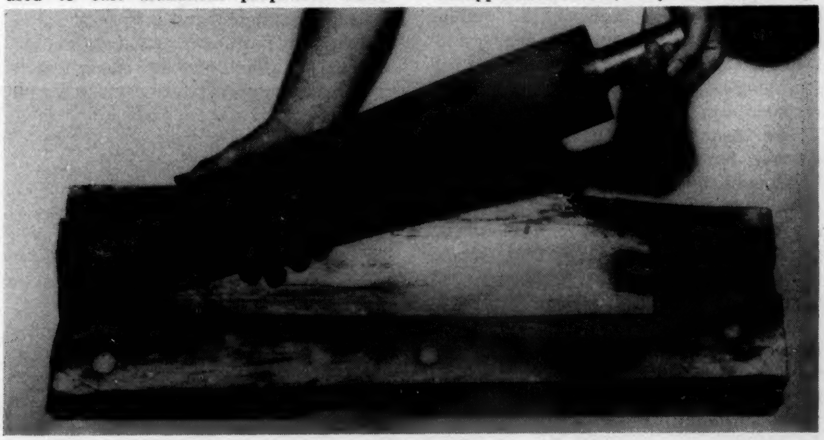
(See photograph on page 8.) It should be noted that at the present time, no other refractory material has been found which is satisfactory for this use. Dimensional stability over large thermal gradients, thermal shock resistance and ease of fabricating large contoured shapes are some of the prime requirements for a material for use as brazing forms on fixtures. Dimensional stability and thermal shock resistance are the two properties most difficult to obtain in ceramic materials.

Of course, fused silica has been known for quite some time and considerable information about its physical properties can be obtained from handbooks. However, it should be remembered that most of this information is for clear fused silica and the fabrication techniques are usually concerned with forming the desired shape while it is in the molten state. Here we are dealing with the same basic material, but it is not in the same physical state. The material discussed here is clear fused silica which has been crushed into fine particles; the particles are then cemented together to form the desired shapes. It should also be noted that the shapes are formed at room temperatures and not at elevated temperatures (3100° F) as is the case with clear fused silica.

The effect of pulverizing the fused silica on the physical properties of the final product can be illustrated by comparing the thermal conductivity of clear fused silica with slip cast fused silica. Clear fused silica exhibits a rapid rise in thermal conductivity above 300° F, whereas slip cast fused silica remains a good insulator up to 2000° F. This difference is attributed to the transmission of radiant energy in the clear fused silica and the diffusion of radiant energy by the small particles of the slip cast fused silica. This fact has allowed slip cast fused silica to be used as reflectors for clear fused silica radiant heating lamps. Thus, the same material has been used for both transmission and reflection of radiant energy.

Another example is the comparative thermal shock resistance. The very low thermal expansion of fused silica allows it to withstand severe thermal shock. Although the thermal expansion of slip cast fused silica is the same as clear fused silica, its thermal shock resistance is actually superior. This is attributed to the fact that numerous very fine particles bonded together provide areas of thermal stress relief which are not present in the solid clear glass.

Shown is half of a permanent foundry mold used to cast aluminum propeller blades. After a dozen castings this mold showed no appreciable wear, may last indefinitely.



Van Toole

by J. D. Fleming, Research Engineer

REACTORS VS. MATERIALS

THE TEMPERATURE ATTAINABLE in ordinary chemical combustion processes is limited by the dissociation temperatures of the combustion products. As a result, power plants using coal, gas, oil, or gasoline will be limited in maximum thermal efficiency. Since the rate of a nuclear fission reaction is roughly independent of temperature, provided the neutron flux is unaltered, a nuclear reactor can maintain any temperature which the material of the reactor can withstand. The thermal efficiency of a nuclear system thus can be many times that of a chemical system.

Because of the high cost of nuclear fuel and the concomitant chemical reprocessing, high thermal efficiency becomes necessary if nuclear energy is to compete with chemical energy prior to the exhaustion of fossil fuel resources. Increased thermal efficiency also results in a decrease in size of a nuclear system for a given power capacity. Aside from considerations of economy then, high thermal efficiencies are necessary for mobile power units, as for nuclear space craft, ship, or aircraft propulsion, because of the lower bulk requirements for the reactor.

The desire for higher thermal efficiencies has stimulated research in the high temperature reactor field. Development of a reliable high temperature reactor is largely a materials development problem since no basic alterations are necessary in the nuclear or power conversion considerations.

Project B-153 is directed toward the development and investigation of materials suitable for use in nuclear systems above conventional temperatures of about 1500° F. Fused silica has been the primary material studied to date as a result of its unexcelled thermal shock resistance, good resistance to radiation damage, high chemical inertness, and low neutron capture cross section. Because of these properties, fused silica should lend itself to applications such as fuel matrices, structural members, reactor components, control and scram rod matrices, and, when foamed, reactor and component thermal insulation.

The major objections in the past to the use of fused silica as an engineering material have been its unusually high cost and the difficulties associated with its fabrication. With the slip casting techniques developed at Georgia Tech, the cost of fused silica has been brought to the level of most commercial refractory structural materials. Also, limitations on the size and intricacy of shape have been essentially eliminated.

In order to permit a complete evaluation of fused silica for reactor applications, data on its engineering properties are being gathered under Project B-153. During the past year, strength characteristics at both room and elevated temperatures, thermal stability, gas retention capability, and radiation resistance have been studied. The project is sponsored by the Atomic Energy Commission.

The tensile and transverse strengths of slip cast fused silica depend markedly on the method used for its firing. The strength would seem likely to be imparted by cross-particle crystal nucleation during firing and be decreased by fracture of the particle junctures during post firing cooling. As a result of this postulated mechanism, the silica was expected to behave in a manner similar in many respects to that of precipitation

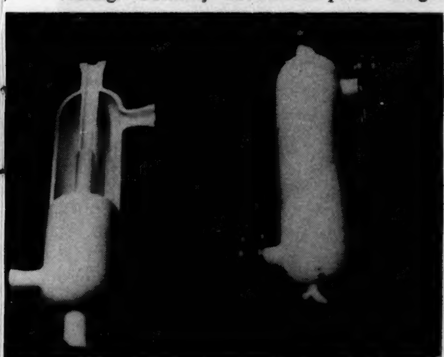
hardening metals. In a series of controlled firing experiments, the expected behavior was observed. The strength did increase to a maximum and then decrease with firing time at a constant firing temperature. Furthermore, indications were noted of an optimum combination of firing time and temperature which would produce a maximum strength.

Elevated temperature tensile testing of the slip cast fused silica surprisingly proved that the strength increases rapidly with environmental temperature. The short time strength at 1800-2000° F was more than double the room temperature strength of about 1500 psi.

One of the most satisfying phases of the past year's work on Project B-153 was the successful development of a system to determine the permeation coefficient, or effective diffusivity, for gas release through the fused silica. In order to yield a high sensitivity, low cost system, a tracer technique was devised. In this system, the sample is clamped between two chambers, one which is initially free of the radioactive krypton tracer gas and the other which contains a small quantity of tracer. Measurement of the activity in each chamber permits calculation of the effective diffusivity.

Mathematical consideration of the unsteady state gas flow process indicated that a very accurate approximation could be made by treating the data as if steady state were actually achieved. The advantages resulting from this experimental technique are that no sample need be withdrawn from the system for analysis, knowledge of the specific activity and quantity of the tracer gas is not required, and the mathematical treatment is exceptionally simple.

Fused silica heat exchangers made by slip casting. Cutaway shows one-piece design.



Samples of slip cast fused silica were irradiated in the Westinghouse Testing Reactor to determine the influence of inpile radiations. Since fused silica is already amorphous, less damage would be expected than is normally observed in the irradiation of crystalline materials such as metals and most other ceramics. The silica samples are now being studied to determine the change in strength and crystalline material content as well as the structural distortion and alteration resulting from the irradiation.

At the request of the Bureau of Mines, a fabrication study was carried out to determine the feasibility of slip casting shell and tube heat exchangers of fused silica. An indication of the complex shapes which can be slip cast is shown by the two exchangers in the accompanying photograph.

During the next year, in addition to a continuation of the past work with fused silica, exploratory investigations will be carried out in the formation of high temperature cermetic fuel elements through thermite reactions. Thermodynamic calculations have indicated that beryllium should reduce uranium dioxide with the liberation of heat. This internal heat generation should be capable of firing the resulting products to form a dense cermetic body. Through the inclusion of elemental or chemically combined carbon, silicon, or nitrogen, a final cermet should be obtained in which beryllium oxide is intimately mixed with uranium carbide, silicide, or nitride. Since beryllium oxide is an excellent moderator and since these uranium compounds are very refractory, the resulting cermet may have good potential as a high temperature nuclear fuel element.

by C. R. Mason
Assistant Research Engineer

Three Hot Problems

THE DEVELOPMENT of high temperature resistant materials for three general areas of application is continuing under Engineering Experiment Station Project A-212. These studies are sponsored by the Department of the Navy, Bureau of Ordnance. They concern thermal protection systems, coatings, and thermets.

Thermal Protection Systems

This phase of the project is concerned with providing thermal protection for structural members in applications where temperatures will be encountered which are far above the melting point of any known material. Some areas of skipglide re-entry vehicles, low altitude cruise missiles, and advanced propulsion systems require protection from extreme temperatures for periods of time ranging from minutes to hours.

These conditions require some sort of material cooling. This may be accomplished by ablative cooling, transpiration cooling, or convection cooling; depending on the length of time that the temperatures must be endured. Transpiration and convection cooling provide the longest protection times and are the two methods that will be considered in the work done under this project.

Forty-KW plasma jet equipment in operation, showing console and jet spray unit.

Hafnium oxide coating is being applied to a fused silica plate for aerodynamic study.

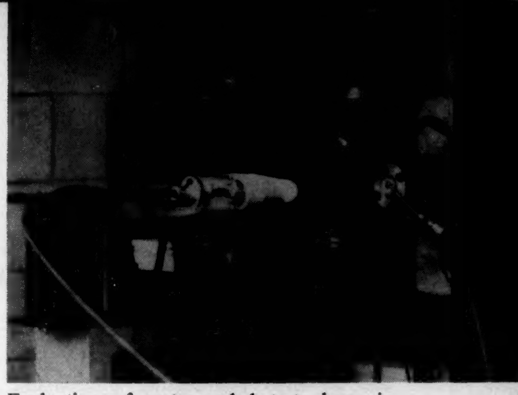
Slip cast fused silica has been selected as the first material to be investigated because of its ease of fabrication and excellent resistance to thermal shock.

During the past year basic thermal and mechanical properties have been determined for various forms of fused silica. Now that these basic data are available, various aerodynamic shapes will be evaluated using the oxyhydrogen rocket motor and the recently acquired plasma jet system. These two pieces of test equipment permit laboratory simulation of heating rates and heat fluxes which will be encountered by hypersonic aircraft and missiles. These shapes will be evaluated to determine the effectiveness of various cooling methods in combination with very refractory protective coatings applied with the arc-spray gun.

Coatings

A new piece of equipment for applying refractory coatings has been put into operation at the Ceramics Branch. The equipment is a 40-KW arc plasma jet. (See photographs on the next page and the cover.) Basically the unit provides an electric arc which can be stabilized with various gases such as argon, nitrogen, and hydrogen so that a continuous heat source is available. Refractory powders are introduced into the "plasma," melted, and sprayed in a molten condition onto a substrate. Normal operating temperatures in the plasma range from 10,000 to 15,000° F. These temperatures are well above the melting point of any known material. Coatings have been obtained from hafnium oxide (MP 5030° F), hafnium carbide (MP 7000 + °F), tungsten (MP 6170° F), and many other super-refractory materials.

The plasma spray work on project A-212 at present is directed towards forming thin refractory shapes rather than applying protective coatings. These shapes are formed by spraying a refractory material onto a suitable pattern. The pattern is removed using one of several techniques that leave a thin shell of arc-sprayed material having the same configuration as the pattern. (Pattern materials and removal techniques are discussed in more detail in the article on rocket nozzle materials.)



Evaluation of water-cooled test shape in exhaust of the oxyhydrogen rocket motor.

Thermets

The word thermet is used to denote a cermet which has been formed using the heat and products of a thermite reaction. A cermet composed of beryllium oxide and chromium metal may be formed by the following reaction:

$$3Be + Cr_2O_3 \longrightarrow 3BeO + 2Cr + Heat$$

Test shapes have been formed from the materials on the left hand side of the above equation by dry pressing. These shapes were ignited by heating them to 2000° F. By using proper throttling materials and ignition techniques, thermets have been formed which have very little porosity, and have transverse strengths approaching 40,000 psi. These test pieces also maintained their shape through the ignition step with negligible warping.

Slip casting techniques are now being developed so that more complicated thermet shapes can be formed.

The development of more refractory thermets is being initiated. These reactions will employ hafnium metal as the reducer and graphite as a carbide former. One such possible reaction is

$$Hf + TiO_2 + C \longrightarrow HfO_2 + TiC.$$

The thermet work during the next year will be directed toward immediate applications of thermets as well as continued investigation of the basic thermet reactions.

by C. R. Mason

ROCKET NOZZLES

TO PUT IT MILDLY, the nozzle of a solid-fuel rocket motor receives a great deal of high temperature punishment. Developing a material to withstand the force of hot rocket blasts is the object of Project A-409, sponsored by the Department of the Navy, Bureau of Ordnance. Slip cast fused silica is the material under study.

Slip cast fused silica is used as the basic nozzle material because of its ease of fabrication, light weight, and excellent resistance to thermal shock. Two methods are being used to provide errosion protection for the fused silica. One method is to arc spray a refractory coating on the fused silica. The other method is to form a refractory shell by arc spraying onto a removable mandrel, and then backing this shell with fused silica.

The first method, applying coatings directly to fused silica, is difficult because of the very low thermal expansion of fused silica. Any temperature change either during coating application or during testing will result in stresses being set up in the coating because of differential thermal expansion. Thin coatings withstand these stresses better than thick coatings, but thin coatings do not provide adequate errosion protection.

Thick coatings can be made to withstand these stresses by using an intermediate coating having a coefficient of thermal expansion which lies between that of fused silica and the outer coating material. Hafnium oxide coatings on fused silica nozzles have withstood screening tests on the oxyhydrogen rocket motor. This system is marginal, however, and will not stand up under the more severe solid-fuel test.

To circumvent the differential thermal expansion problem, the coating material is formed into a nozzle shell and this shell is then backed up with fused silica. The silica will thus strengthen the shell but the shell will be somewhat free to move independantly of the back-up material so that stresses in the shell due to expansion will be reduced.

Several methods are available for forming arc-sprayed shells. Some of these methods are:

1. The shell is arc-sprayed onto a metal mandrel and the mandrel is then either leached away with a suitable acid or melted away.

2. Similar to 1 above except a releasing agent is used so that the sprayed material does not adhere to the mandrel. The mandrel may be made in one piece

Solid propellant rocket motor used to evaluate nozzle materials is in concrete bunker.

and pulled apart at the throat section or it may be made to screw apart at the throat. (See the cover photograph.)

3. The shell is sprayed onto a graphite mandrel and the graphite is removed by burning.

The above methods and variations of them may be used to form thin arc-sprayed shapes other than rocket nozzle shells.

Evaluation of rocket nozzles is accomplished using the Ceramics Branch's two rocket motor facilities. The nozzles are screened using the oxyhydrogen rocket motor. The nozzles that pass the screening test are then evaluated in a solid fuel motor. This solid fuel motor operates on one of the more advanced solid fuels, and on a small scale it provides a realistic nozzle test.

by N. E. Poulos

Man-Made Meteor—The Nose Cone

ENGINEERING Experiment Station Project A-330 (sponsored by U. S. Army Ordnance, Redstone, Alabama, under Contract No. DA-O1-009-ORD-548) which was begun April 1, 1957, was concerned with the development of materials for resistance to high velocity erosion at high temperatures.

The work on this project was previously reported in the October 1957 and the December 1958 issues of the *Research Engineer*. A brief review of the work is presented here.

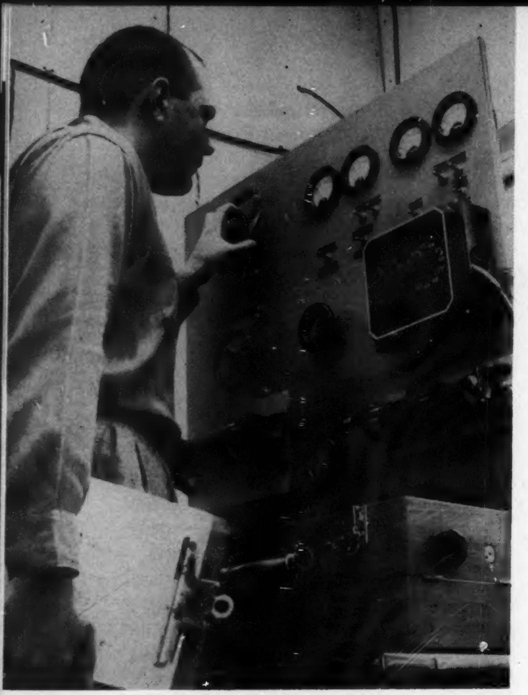
The work that was carried out was primarily devoted to basic studies of ceramic body compositions and the fabrication of nose cones from the most promising ceramic composition developed from the basic studies.

One of the prime requisites for a ceramic nose cone material is that it must withstand a sudden or instant heating from a relatively low temperature to a very high temperature, i.e. from 32° F to 5000° F in a few seconds. Most ceramic materials fail explosively upon being subjected to such extreme thermal shock. Fused silica, however, can withstand such shock without failing and, therefore, was selected for use as the basic ceramic nose cone material.

The fused silica used in this case was in the form of a slip (finely divided particles suspended in some medium such as water) from which suitable shapes can be cast in plaster molds. Thus, it became possible to take advantage of a conventional ceramic forming technique which has been used for many years by the ceramic industry in the production of numerous ceramic items.

In studies of basic body compositions preliminary emphasis was placed on increasing the strength of the slip cast fused silica bodies. The effects of grain size distribution, firing time and temperatures and firing procedure on the strength of slip cast fused silica were investigated. The effect of various additives to fused silica slip on its strength, melting point and thermal shock resistance were also investigated. These additives were either mixed with the slip, or the cast fused silica slip was impregnated with the additives by vacuum-pressure techniques.

After the development of a nose cone with suitable strength and which withstood the exhaust blast of an 18,000-lb thrust rocket motor, attention was turned toward the development of compositions based on fused silica which would provide maximum thermal protection. In order to accomplish this it was necessary



Special instrumentation is used to measure thermal conductivity during nose cone tests.

to construct the necessary apparatus to measure thermal conductivity at high temperatures.

The illustration shows the thermal conductivity apparatus which was constructed to measure thermal conductivity in excess of 1600° F. This apparatus is a modified design of the guard-ring type unit used in the American Society of Testing Materials' C177-45. The design modifications extend the temperature range of the device to 2000° F, and eliminate the need of cumbersome equipment for measurements of thermal conductivity of various refractory-type materials with a maximum error of ± 5.6 per cent.

Nose cone shells exhibiting good strengths, excellent thermal shock resistance, and excellent dimensional stability have been successfully cast in plaster molds using fused silica slips.

Large shapes were cast with little difficulty and it appears that any sized shape can be easily fabricated with fused silica slip. These developments resulted in the successful conclusion of the contract on April 1, 1959.

by J. D. Walton

A PREDICTION FOR RADOMES

As a result of the large amount of work which has been done at the Ceramics Branch related to slip cast fused silica a great deal of data has been gathered which suggests the use of this material for radomes. However, before presenting these data it should be pointed out that several operational parameters should be anticipated for a missile before slip cast fused silica would be considered as a radome for that missile. The more important considerations are:

1. Temperatures to be encountered during flight, as a result of aerodynamic heating, from 1500° F to above 2000° F.
2. Heating rate sufficiently high that other ceramic materials fail from thermal shock.
3. Size of radome (in excess of 6-8 feet in length) such that fabrication from other ceramic materials is essentially impossible or cost is prohibitively high.

It may be said, therefore, that for applications where other materials are

performing satisfactorily and size and high heating rates are not a problem, there would be little reason for considering fused silica.

Before any material can be considered for radome applications, the dielectric properties must first be determined. The dielectric constant and loss factor of slip cast fused silica at 10^{10} cps are given for several temperatures in the accompanying table. These electrical properties of slip cast fused silica are considered excellent for radome applications and are less affected by temperature than are other ceramic radome materials.

Temp.	*Dielectric Const. at 10^{10} cps*	*Loss Factor at 10^{10} cps*
75° F	3.17	0.0002
1500° F	3.18	0.0006
2015° F	3.28	0.007
2500° F	3.42	0.012

The transverse strength of slip cast fused silica is in the range of 4,000 to 6,000 psi, as compared with 20,000 to 40,000 psi for aluminum oxide. However, the dielectric constant is such that a half-wave wall of this material would be approximately 0.45 inches for 10^{10} cps, which is roughly twice that for aluminum oxide. Therefore, for comparison purposes the transverse strength of slip cast fused silica should be doubled, or considered to be between 8,000 and 12,000 psi.

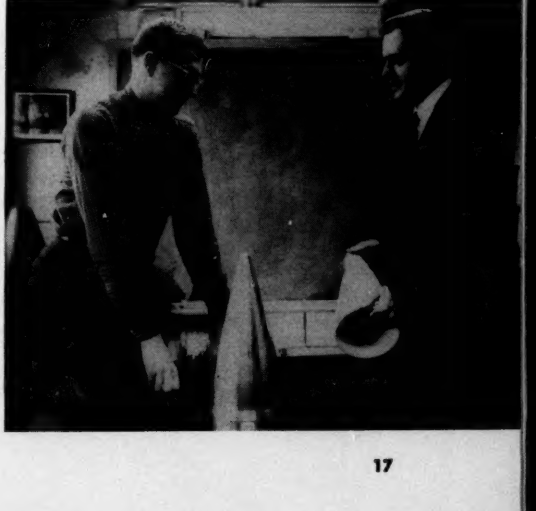
While on the subject of strength it should be mentioned that slip cast fused silica increases in strength with increasing temperature. At 1800° F it is 2 to 3 times stronger than it is at room temperature. Aluminum oxide, on the other hand, decreases in strength by a factor of 2 over the same temperature range. Thus, it would be expected that at elevated temperatures slip cast fused silica may be as strong or perhaps stronger than aluminum oxide. Thus, for actual flight conditions at these temperatures where thermal gradients would be encountered, the slip cast fused silica should be considerably stronger than aluminum oxide due to its much lower coefficient of thermal expansion.

It is fortunate that the specific gravity of slip cast fused silica is only 1.9 gm/cc. This means a radome of this material would weigh almost exactly the same as one of aluminum oxide although it would be twice as thick. Add to this the fact that the thermal conductivity of slip cast fused silica is an order of magnitude less than aluminum oxide, and it becomes evident that a great deal more thermal protection can be provided for the system contained within the radome.

When considering thermal shock resistance, it can be stated that thermal conditions have not yet been encountered which have caused slip cast fused silica to fail. Heat fluxes over the range of 2,000 Btu/ft^2-sec to 50 Btu/ft^2-sec have been used in the evaluation of this material without a single thermal shock failure noted.

By combining these properties with ease of fabrication, this material becomes even more attractive. The radome shown in the accompanying photograph was slip cast in a plaster mold made from the aluminum mandrel which is also shown. The total linear dimensional change due to drying and firing shrink-

J. D. Walton (right) shows J. D. Fleming fused silica radome, cast using aluminum mandrel.



age was one per cent. Nose cones of the size shown in the background which are 2½ feet tall have been slip cast and successfully tested in the exhaust of an 18,000-lb thrust rocket motor.

The primary objection to the use of slip cast fused silica for radome applications has been its poor rain erosion resistance. It is apparently as good as the best of the reinforced plastics but an order of magnitude poorer than aluminum oxide.

However, as mentioned earlier, slip cast fused silica would only be considered for applications where very high heating rates and very high temperatures are to be encountered. It is our belief therefore, that the rain erosion resistance of a material which will not survive these high heating rates is of no consequence and that a material which will survive must be selected for use under these conditions regardless of its rain erosion resistance.

by J. D. Walton

A New Approach to the Problems of TELESCOPE REFLECTORS

ASTRONOMERS, astrophysicists, and other scientists seeking knowledge from beams of light that have sped through space for thousands and millions of years find that the materials available on Earth cause some of their greatest problems. In order to gather and focus the weak light from distant galaxies large telescope reflectors are needed—the larger the better. Yet the physical properties required of telescope reflectors are so restrictive that only a few materials have been considered as feasible for their construction. The largest ever made is Palomar's pyrex reflector, which measures 200 inches in diameter.

However, fused quartz has long been recognized as the near ideal material from which to fabricate reflectors for astronomical telescopes. Manville,[1] in discussing the desired physical properties of materials to be used for reflectors, states: "If density and specific heat are taken into account in addition to thermal conductivity and coefficient of expansion, a merit figure is obtained which indicates how mirrors of given proportions, but of different materials, are affected by temperature changes. To illustrate, . . . a fused quartz disc would return to its normal shape seven times as quickly as one made from speculum metal, the characteristics of which make it in turn about four times as good as 'Pyrex' in this respect; whilst 'Pyrex' is also seven times as good as crown glass. Unfortunately, fused quartz, the best material, is not yet available in

sizes required for very large mirrors, though it is hoped that future developments will remedy this position."

Woodbury[2] described the efforts of Professor Thomson and A. L. Ellis of General Electric to construct the 200-inch reflector for Palomar of fused silica. After two years of exhaustive effort and an expense of $600,000 they had to abandon their project, although they had not yet successfully made a 60-inch reflector. It was estimated that should it be possible to form the 200-inch reflector, the cost would be close to two million dollars.

During the past two years much work has been done at Georgia Tech in developing a method for slip casting fused silica. This technique differs from the previously used methods in that the fused silica is not worked or formed into the desired shapes while in the molten condition (above 3100° F). While in the molten condition the liquid is so viscous that it is impossible to remove entrapped air, and therefore special techniques together with the use of clear rock quartz crystals need be employed to produce a bubble free glass. Consequently this method is very costly and quite limited as to the size and shape of articles which can be manufactured.

The method used at Georgia Tech employs the use of silica which has been melted without regard to final size, shape or entrapped air. This lump form of fused silica is pulverized by grinding in water with desired additives to provide a suspension of finely divided fused silica. The maximum particle size of the suspended particles is 44 microns, while 20 to 30 per cent is smaller than 2 microns. In the ceramic industry such a suspension is referred to as a slip, and the technique of manufacturing ceramic articles from a slip is known as slip casting.

It should be noted that the total linear shrinkage accompanying the drying and firing of the slip cast fused silica is between 0.5 and 1.5 per cent. Thus, it can be seen that very close tolerances may be obtained in the "as cast" condition, allowing for a minimum of excess material to be removed in the grinding and polishing operations.

The final article thus formed has some of the most desirable properties of the fused silica articles produced by the old method of forming the molten silica. The thermal expansion and specific heat are the same, the density and thermal conductivity are less. The slip cast product is porous.

The porous nature of the slip cast fused silica would be undesirable when considering an optical surface. However, by the proper use of ethylsilicate and/or colloidal silica it would be expected that the void size, at least on the surface, could be reduced to the order of a few millimicrons, thus providing a surface of sufficient smoothness to be considered suitable for grinding and polishing to an optical finish.

A feasibility study was undertaken in April of 1959 to establish the validity of constructing astronomical telescope reflectors from slip cast fused silica. It was found from this study that although the void diameter may be sufficiently small to theoretically produce an optical surface, considerable difficulty is encountered in polishing through particles without the particles being removed from the surface. Thus the particle diameter, rather than void diameter, became the limiting factor. Although the bond strength may be improved, which will in turn reduce the tendency for the particles to be removed, it is doubtful that the degree of strength or reliability which is required for such an exacting science will be achieved.

It is therefore anticipated that this material may best be used for relatively small reflectors where very deep or otherwise difficult to polish contours are required, or as a back-up or structural support for the fabrication of composite reflectors.

[1] G. E. Manville, "Mirrors for Large Astronomical Telescopes," *J. Soc. of Glass Technology.* Vol. 39 71N-76N (1955).

[2] David O. Woodbury, *The Glass Giant of Palomar*, Dodd, Mead and Company, 1939.

by N. E. Poulos

CERAMIC TOOLING

IT HAS BEEN REPORTED that the air frame of future aircraft will no longer be made of aluminum. This results from the fact that supersonic aircraft which will fly at speeds in the mach 2 to mach 4 range will develop temperatures of between 300 and 1000° F on their leading edges. The use of aluminum becomes prohibitive when considering temperatures above 500° F. The construction of supersonic aircraft that will withstand these temperatures, however, presents quite a problem. The transition from subsonic aircraft to supersonic aircraft has been so rapid that research and development in materials and structural design has not kept pace with the advances in engines and aerodynamics.

At the present time a metal that is being considered as a structural material for the air frame is high strength, heat treatable stainless steel such as 420. Although such a material offers a solution to the aerodynamic heating problem, the actual fabrication of an aircraft from such a material has presented numerous problems. For example, if the steel is formed in the annealed state to the desired contour, it is warped when it is subsequently heat treated to obtain desired structural properties. If it is first heat treated it is then too brittle and hard to be formed into desired contours. However, if the steel could be simultaneously heat treated and formed, this particular problem could be solved.

One method that has been considered for accomplishing simultaneous heat treatment and forming is the use of ceramics for the forming dies. However,

A new material permits simultaneous forming and heat-treating of stainless steel, an important metal for modern aircraft

if ceramics are used, two problems that immediately become evident are (1) severe thermal shock will be imposed on the ceramic by being placed into a heat treating furnace which is at 1700-1800° F, and (2) a long period of time will be required for the heat to soak through the ceramic which is normally insulative.

The Georgia Division of the Lockheed Aircraft Corporation has been actively engaged in a project to develop a technique to simultaneously heat treat and form stainless steel. Their approach has been to heat the steel by resistance heating to the desired temperature and then form the desired contour by closing ceramic dies over the steel sheet. The use of this technique fully utilizes the insulative qualities of the ceramic dies. (See the accompanying photographs.)

The material selected by Lockheed for use for the forming dies was a ceramic castable of bonded fused silica. This material satisfied the two properties of primary importance—thermal shock resistance and good insulating qualities. Lockheed sponsored a project at Georgia Tech for the purpose of developing ceramic compositions for tooling applications. This work was concerned primarily with the use of fused silica grain or aggregate, bonded by fused silica or other suitable cements and binders.

Once the problems of insulation and thermal shock resistance were solved, the requirements of forming ease, low total shrinkage, dimensional stability and absence of warping due to differential heating were met by the compositions developed at Georgia Tech.

Left. Equipment for simultaneous heat-treating and forming stainless steel is shown in operation. White part is fused silica die. *Below.* Test piece exhibits double curvature.

Photographs Courtesy Lockheed Aircraft Corp.

by J. N. Harris
Assistant Research Engineer

A Successful Study of

STEEL, PORCELAIN AND FISHSCALE

MARINE EXHAUST MUFFLERS, snorkel tubes and other shipboard components are frequently porcelain enameled for protection from corrosion. In the event of a national emergency, the common metals that might be available in plate thickness, such as rimmed, killed and semi-killed steel, may cause many defects in porcelain enamel coatings applied to them. The determination of factors affecting the enameling characteristics of steel plate, and the development of a method for qualifying steel plate acceptably receptive to porcelain enamel coatings are the objects of Project A-413.

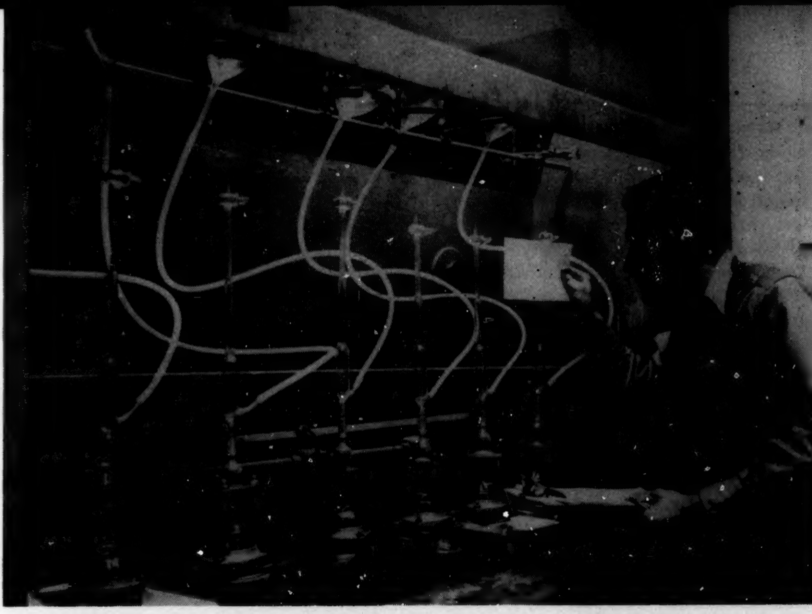
Porcelain enamel, a glass coating fused to metal, has a texture between that of a flat paint and a smooth glass. The most common defect encountered in enamels on steel plate (of the type to be used in ships) is fishscaling. Fishscaling is the spontaneous fracturing of the glassy coating, exposing the metal underneath. The defect is usually shaped like a fishscale, hence the name. Fishscaling may not show up for days or weeks and often the enameled article is put into service in this potentially defective condition.

Fishscaling has been attributed to gases occluded by the steel which are subsequently precipitated at the enamel-metal interface after the enamel has cooled. Analysis of the gases indicate that hydrogen is the most abundant gas present. The hydrogen apparently is injected into the steel at enameling temperatures by the reaction between the steel and the chemically combined water in the frit and the clay component of the enamel composition.

Many researchers have tried to discover why, when two similar steels have been coated with the same enamel, one will produce fishscale while the other remains in good condition. However, the exact reasons have not been determined.

At the present time the best method for qualifying steel plate appears to be the application of a "standard qualifying enamel" to samples of steel plate from each lot. By heating the enameled plates to 225° C for 48 hours any delayed fishscaling defects will show up. By heating the enameled specimens to 900° F and quenching them in water the adherence of the enamel to the metal can be determined.

A "reagent" or "standard qualifying enamel" should be a coating as free from fishscaling tendencies as possible. Commercial frits may vary somewhat from batch to batch and the commercial frit companies may discontinue production of a certain frit at any time. For these reasons either a large quantity of commercial frit, preferably from the same batch, would have to be stored in a government laboratory, or reagent frits would have to be smelted under laboratory conditions. A part of the work under A-413 was devoted to laboratory smelting of reagent frits. However, it was concluded that it would be more practical to pur-



APPARATUS ABOVE EXTRACTS AND MEASURES GAS FORMED BY ENAMELING.

chase large quantities of the reagent frit from a commercial source than to smelt laboratory batches since a problem would arise as to whether each facility which smelts the prescribed batch would have identical smelting conditions.

In preparing the mill batch of porcelain enamels, reagent materials can be used in all cases except for the clay used as a suspension agent. Unfortunately, clays are naturally occurring and cannot be as closely controlled as reagents synthesized in the laboratory.

A relationship exists between the structure of an enamel called the bubble stratum and its tendency to fishscale. An enamel that has large uniform bubbles closely spaced has less tendency to fishscale than an enamel with small, poorly defined bubbles. This may be attributed to the facts that the large bubbles provide collection chambers for the hydrogen and/or the large film area provides stress relief.

The condition of the bubble stratum depends on variables such as firing temperature and time. The most important variable in the formation of the bubble stratum appears to be the type of clay used in the mill batch. Past experience has shown that clays purchased from the same manufacturer under the same clay number at different times have imparted different properties to enamels made with these clays.

Eight enameling clays were obtained and each milled with a standard mill batch. These enamels were applied to C1012 steel and fired under identical conditions. The bubble films of the enamel coatings were then observed under a low power microscope. Differential thermal analyses were made on each of the clays to determine the amount of chemically combined water contained in each.

By comparing the differential thermal analysis curve for each clay with the bubble stratum in the enamel containing that clay, it was determined that clays containing the largest amounts of chemically combined water produced the best bubble strata. From this study it is believed that differential thermal analysis is sufficient to determine a reagent clay for a standard qualifying enamel.

A number of steel plates 3/16 and ¼ inch in thickness were secured from sev-

eral manufacturers. Samples from each of these plates were coated with the standard qualifying enamel. Gas extraction, accelerated fishscale and thermal quench studies were carried out on each steel. From the results of these studies only two steels failed to qualify. Samples of all steels obtained were then coated by a commercial firm which manufactures marine mufflers. The two steels which failed the qualification studies at Georgia Tech developed delayed fishscale after being coated with the commercial coating. The coating on all other steels remained in good condition.

It is therefore felt that, although this result does not represent the desired scientific solution to the question of why certain steels produce fishscales, it does provide a method whereby suitable steels may be qualified as being suitable for porcelain enameling.

by J. N. Harris

For Electrical Insulation: A FLEXIBLE CERAMIC

THE HIGHER TEMPERATURES encountered by missiles and aircraft have placed a severe load on electronic components inside them. On February 1, 1957, a project was initiated at the Engineering Experiment Station to develop a high temperature electrical insulation for copper wire, capable of withstanding temperatures up to 1500° F. This research is supported in whole or in part by the United States Air Force under Contract AF-33 (616)3944 and monitored by the Materials Laboratory, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio.

The electrical properties required for this insulating coating include high dielectric strength, low loss tangent and low dielectric constant. The physical properties required are operating temperatures of 85° F to 1500° F, flexibility, abrasion resistance, thermal shock resistance and corrosion resistance.

Since flexibility is not one of the attributes of normal ceramic coatings a new approach to this problem had to be undertaken. The need for flexibility of a wire insulation would be during initial installation at room temperature; once installed there would be no further need for flexibility. Our approach was to combine an organic and an inorganic coating in the form of a silicone resin with a powdered glass filler. The resin would provide the necessary initial flexibility. Once this insulation system is heated up, the resin should burn out and the powdered glass filler should fuse, forming a continuous coating to 1500° F.

But a glass that will fuse at the burnout temperature of the resin will be in a viscous liquid state at 1500° F and will act as a conductor. The attempt to solve this problem was to use a non-fusing porous base coating and to apply the resin-glass enamel coating over the base coating as a sealer against moisture. The major portion of this year's work has been carried out in developing this base coating.

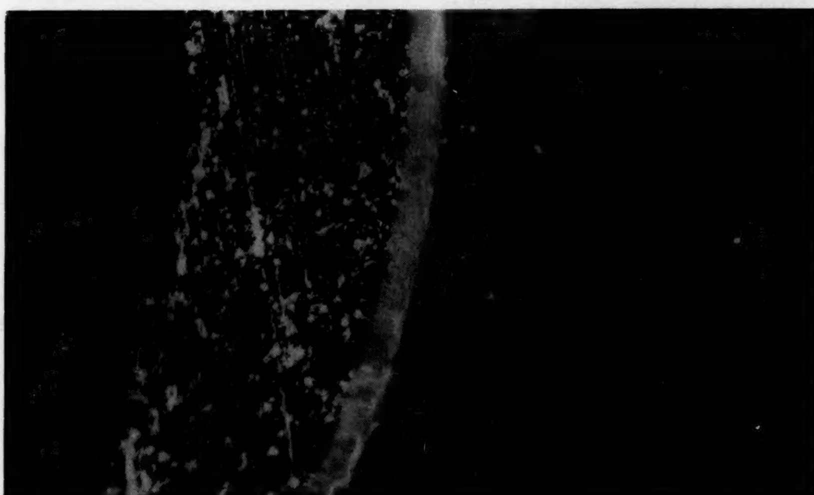
The best base coating thus far obtained has been aluminum oxide, obtained by anodizing a layer of aluminum over the copper base metal. Some work was carried out on cladding copper wire with aluminum in our laboratory. However, since two commercial companies are now manufacturing aluminum clad copper wire it was decided to obtain aluminum clad wire from these sources and to apply a major effort to the anodizing of these wires.

The greatest flexibility was obtained from wires anodized in phosphoric acid. Wire anodized in this electrolyte could be bent around a mandrel less than ten times the diameter of the wire without cracking the coating. This flexibility is possible due to the porosity of this coating. Aluminum oxide crystals are long columnar crystals and the pore openings in this type of anodized film are numerous and relatively large. The pores allow the long columnar crystals room to flex without touching the other crystals. This type of anodized film had good electrical properties and could be sealed with frit-resin or with colloidal silica from ethyl silicate coatings.

The aluminum-clad copper wire obtained commercially consists of a copper core plated with a thin film of nickel or silver and then clad with aluminum. On the 0.0201-inch diameter wire the thickness of the aluminum cladding is approximately 0.002 inches. Normally the phosphoric acid anodizing is only 0.3 to 0.5 mils in thickness. This leaves a considerable thickness of aluminum that is not anodized. Above 800° F this unanodized aluminum alloys with the copper greatly reducing the electrical conductivity of the copper and making the wire very brittle. For this reason it will be necessary to anodize all but a very small percentage of the aluminum.

Efforts were made to strip all but 0.5 mil of the aluminum from the aluminum clad wire so that the phosphoric acid anodizing could convert the remaining aluminum to aluminum oxide. This technique did not prove to be very satisfactory since the aluminum was not removed evenly from the wire by the stripping solution.

By anodizing in sulfuric acid, advantage was taken of the solvent action of the sulfuric acid on the aluminum oxide. By using proper current densities and anodizing times it was possible to anodize all but 0.3 mil of aluminum. This technique produced an anodized coating of 0.8 to 1 mil in thickness. Such anodized coatings do not have the flexibility of the phosphoric anodized coating, but they can be bent around a mandrel from 12 to 16 times the diameter of the wire without spalling. Although greater



Cross-sectional view of insulated wire is seen in this micrograph. Left to right are: copper core, unanodized aluminum cladding, anodized aluminum layer, frit-resin sealer.

flexibility would be desired this is not a serious problem at this stage in the development of wire insulation since the flexibility of the anodized coating is as good as the frit-resin coating applied to it.

Electrical measurements on continuous lengths of sulfuric anodized aluminum clad copper wire show a dielectric constant as low as 3.46 at 0.4 kilocycles with a dissipation factor of .44, and a dielectric constant of 3.12 at 100 kilocycles with a dissipation factor of 0.30. This wire has a breakdown median voltage of 200 at 800° F. A cross sectional view of this wire is shown in the accompanying photomicrograph. Visible are the copper core, the unanodized aluminum cladding, the aluminum oxide layer and the frit-resin sealing coating.

The properties of this coating are as good and in some cases better than many of the high temperature insulations presently available. If the problem of completely anodizing the aluminum cladding copper wire can be solved it should be possible to achieve a 1500° F electrical insulation.

CERAMICS BRANCH continued from page 5

includes a 100 sq. ft. laboratory devoted entirely to plaster mold work and slip casting. A small radioisotope laboratory of 240 sq. ft. was constructed and equipped for use in our nuclear ceramic work. In addition, office space was increased by 450 sq. ft. to provide critically needed space for the 20 additional people added to the Ceramics Branch staff during the year. These brought the total number of employees to 50, of which 13 are graduate engineers.

The latest facility to be added to the Ceramics Branch is a 40 KW arc plasma jet unit. This plasma jet has been used entirely for the development and study of arc sprayed coatings and shapes.

Two new facilities are contemplated for 1960. One is an 80 KW arc plasma jet and wind tunnel which will be used in extending our capabilities for studying, developing and evaluating materials for nose cones, re-entry satellites, leading edges, radomes and other applications where aerodynamic heating will be encountered. The second facility, which is in the planning stage, will make use of a J-65 jet engine to simulate less severe aerodynamic heating conditions for the evaluation of materials fabricated into large shapes. With this facility it is hoped that the thermal and mechanical stresses which will be encountered in high speed flight can be produced in large, and in some cases full-scale models of radomes.

The Ceramics Branch has been an active member of the High Temperature Inorganic Refractory Coatings Working Group which is monitored jointly by WADC and NASA, and is composed of 60 members of industry, government and research institutions. It is the purpose of this group to bring together those who are active in the development and study of coatings for use above 2500° F, to describe their work and exchange information in this field. We have also been active in a sub-committee of this group to develop and standardize arc plasma jet facilities for the screening of materials for aerodynamic heating applications.

The following technical papers were presented or published in 1959:

(1) "Cermets from Thermite Reactions," by J. D. Walton and N. E. Poulos, published in the *Journal of the American Ceramic Society,* Vol. 42, No. 1, January, 1959, pp. 40-49.

(2) "Fused Silica — A Material for Thermal Protection Systems," by J. D. Walton, presented at the Semi-Annual Meeting of the American Rocket Society, June 8-11, 1959, San Diego, California.

(3) "Quantitative Determination of Effective Diffusivities by Tracer Techniques," by J. D. Fleming, J. W. Johnson and H. V. Grubb, submitted for publication Oct. 28, 1959 to *Chem. Eng. Progress.*

(4) "Ceramic Tooling and Honeycomb Brazing Fixtures for Supersonic Aircraft Production," by J. D. Walton and N. E.

DUSTY SLIP-CASTING OPERATIONS ARE DONE IN SEPARATE BUILDING.

Poulos, presented at the Fall Meeting of the Southeastern Section of the American Ceramic Society, November 6-7, 1959, Augusta, Georgia.

(5) "Experimental Application of Arc and Flame Sprayed Coatings," by J. D. Walton and C. R. Mason, presented at the First Aerospace Finishing Symposium, Dec. 8-9, 1959, Fort Worth, Texas.

(6) "Ceramics for High Temperature Electrical Applications," by J. D. Walton and J. N. Harris, presented at the Second Conference on the Application of Electrical Insulation, Dec. 8-11, 1959, Washington, D. C.

The following papers are scheduled for presentation in 1960:

(1) "The Use of Thermite Reactions to Produce Refractory Cermets," by J. D. Walton, N. E. Poulos, C. R. Mason, to be presented at the A.I.Ch.E. Meeting Feb. 21-24, 1960, Atlanta, Ga.

(2) "Heat Transfer from Thin Gold Films to Water in Swirling Flow," by J. D. Fleming and H. V. Grubb, to be presented at the A.I.Ch.E. Meeting Feb. 21-24, 1960, Atlanta, Georgia.

(3) "The Effect of Thermal Stresses on the Mechanical Properties of Engineering Ceramics," by J. D. Walton, to be presented at the First Conference on the Mechanical Properties of Engineering Ceramics, March 9-11, 1960, N. C. State College, Raleigh, N. C. M. D. Bowman is co-author.

(4) "Rocket Nozzles," by J. D. Walton and C. R. Mason, to be presented at the 16th Annual National Association of Corrosion Engineers Conference, March 14-18, 1960, Dallas, Texas.

(5) "Present and Future Problem Areas for High Temperature Inorganic Coatings," by J. D. Walton, to be presented at the 62nd Annual Meeting of the American Ceramic Society, April 24-28, 1960, Philadelphia, Pa.

(6) "Slip Cast Fused Silica — A New Ceramic Material," by J. D. Walton and N. E. Poulos, to be presented at the VIIth International Ceramic Congress, May 23-28, 1960, London, England.

The articles in this magazine give a review of the research and development work carried out by the Ceramics Branch in 1959.

The Ceramics Branch is looking forward to the Sixties as the decade of high temperature materials. For our group, the decade will mark a change in emphasis from the development and engineering of refractory materials to basic research in high temperature materials for the future. We acknowledge the fact that our engineering work has provided us with the staff and facilities which allow us now to consider a more basic program for the future. We will of course continue work in the engineering and development field, but we believe the time has come to emphasize the need for more basic work.

Edited in Retrospect

ramblin' rocks

• In this issue, President Harrison makes reference to the work of Dr. M. R. Carstens, who is serving with the Southeast Asia Treaty Organization in Bangkok. Dr. Carstens is an outstanding educator and researcher, and may be remembered by our readers as the author of "Spillways for Iran" (*Research Engineer,* April 1959). He is also the third member of Georgia Tech's Civil Engineering staff to be called to major overseas assignments in the last five years. Civil engineering seems to be our most exported talent.

the clay's the thing

• It is noteworthy that in this issue devoted entirely to research in ceramics there is not a single mention of pottery, chinaware, or other products most commonly associated with the word "ceramics." This is not a deliberate omission, but rather a result of the fact that now the major challenges for ceramics lie in other areas. Mr. Walton's opening article, "Ceramics in the Sixties," is recommended to the reader's attention. It presents a rather startling look into the future of one of the oldest technologies of mankind.

anniversary volume

• Your editors are also looking forward to a larger and more varied *Research Engineer,* which begins its fifteenth year with this number. Our challenge is to keep pace with the growth of research at Georgia Tech, and to present some of the representative achievements in meaningful articles. We will greatly appreciate the continued comments of our readership about how well or how poorly we meet these objectives.

For the next issues we are planning articles on several subjects new to this magazine. One of these will be on the art of electroforming, a plating process that should prove useful for several southern industries. At least one of the projects using the unusual new facilities of the Radioisotopes and Bioengineering Laboratory will be described. Series of articles are also planned on our latest work in high-speed computation and the research reactor project.